The resistible effects of Coulomb interaction on nucleus-vapor phase coexistence

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We explore the effects of Coulomb interaction on phase transitions in nuclei. Because large nuclei are metastable, phases, phase coexistence, and phase transitions cannot be generally defined. It is possible to account for the Coulomb interaction in the decay rates and obtain the phase diagram for the corresponding uncharged system.

We introduce Coulomb interaction in the problem of a drop and its vapor. The Coulomb interaction can be split into three parts: 1) the drop self energy; 2) the drop-vapor interaction energy; and 3) the vapor self energy. The drop self energy, for a finite bound or metastable drop, does not constitute a problem.
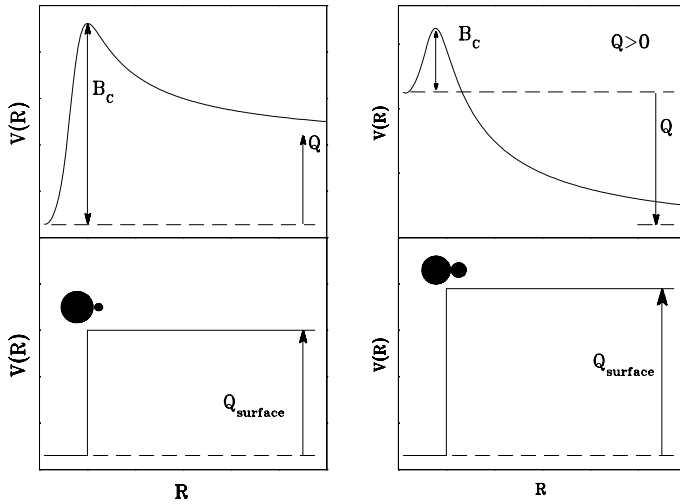

FIG. 1: The Coulomb correction when the emitted cluster is bound (left panels) and unbound (right panels). In both cases one can remove the Coulomb energy of the saddle configuration and calculate the Q value using surface energies only (bottom panels). The resulting hypothetical gas is composed of cluster that are bound to the drop ($Q_{\text{surface}} < 0$).

For the drop-vapor interaction, consider a cluster moving from the drop interior to infinity as shown in Fig. 1. If the cluster has charge $Z = 0$, a step equal to the cluster binding energy Q is observed at the dropl radius. For small $Z > 0$ a maximum B_c is observed at the contact distance of the two, then the potential decreases via the Coulomb law to Q at infinity. In this case, for bound clusters ($Q < 0$) and forgetting 3), B_c does not alter equilibrium and a gas phase in equilibrium with a drop at infinity can be defined. The vapor pressure is described by the Clapeyron equation $dp/dT = \Delta H_m/T \Delta V_m$, ΔV_m is the molar volume and the molar enthalpy ΔH_m accounts for surface and Coulomb terms.

When a cluster becomes unbound to the drop due to Coulomb the situation becomes that of Fig. 1 top, right. The drop is not stable and the ground state may consist of two or more pieces at infinity. This is true at $T = 0$. Thus it is impossible to speak of this drop in statistical equilibrium with its vapor. Our point is made from energy rather than free energy considerations and may be incorrect. Consider the transition from a liquid phase to a vapor phase: for an infinitesimal isothermal transfer $\Delta F = \Delta E - T\Delta S = 0$. For most fluids going from liquid to vapor $\Delta E > 0$ but is compensated by $\Delta S > 0$ due to the increase in V_m. Due to Coulomb ΔE is negative, then for $\Delta F = 0$ $\Delta S < 0$, incompatible with expansion. For a drop with unbound channels a statistical equilibrium first order phase coexistence/phase transition is undefinable.

Consider part 3), namely the vapor self energy which diverges for an infinite amount of vapor. For a dilute vapor, we could consider a small portion so that the self energy/nucleon is less than the temperature T or we could consider a finite box containing a finite system. However, at any distance smaller than infinity the result depends on the size and shape of the container and on whether or not the drop is confined in a specified location of the container. Thus Coulomb makes the definition of phase coexistence and phase transition intractable and ill-posed. A solution to these difficulties can be arrived at by obtaining experimentally the signal and characterization of the phase diagram (transition) of a nucleus as if the Coulomb interaction were absent.

A cluster leaving the drop is boxed in by B_s which depends on the cluster and the residual drop. The top of B_s is similar to the potential of cluster and residual in near contact and is a conditional saddle point in the sense that the mass asymmetry is frozen [1]. According to transition state theory saddles are in equilibrium with the drop and the decay rates give information on their population which is controlled by $\exp(-B_s/T)$. For large enough B_s the experimental yields are related to first chance emission and thus to the transition state rate. B_s depends on the surface and Coulomb energies of the saddle and ground state configurations. Coulomb energies can be estimated assuming two touching spheres for the saddle and one sphere for the drop (see Fig. 1), we correct the rates by dividing away the Coulomb term and be left with only the rates/abundances pertaining to the decay of an uncharged drop, with no unbound channels (see Fig. 1).

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[1] L. G. Moretto, Nucl. Phys. A247, 211 (1975).